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An Electronic Sea-Wave Recorder

V. Narayana Rao

Abstract—This article describes a surface type of sea-wave recorder which is based on the principle of the variation in the capacitance between the sea water and an insulated wire placed vertically in it with changes in the level of the sea water. This change in capacitance is used to modulate the frequency of an oscillator. An electronic unit is used for recovering from the frequency modulated signal an electrical voltage which is an exact replica of the sea wave. This electronic unit is described in detail. The type of recording suitable for various applications and also the performance characteristics of this instrument are also discussed.

Introduction—In order to understand the nature of the sea waves, their characteristics, their influence, and the information they convey, it is necessary to record these waves and to carry out an analysis to estimate their spectrum, significant wave height, and mean significant period. Similar wave recording is also required for experimental studies on models of harbors and beaches. Several types of wave recorders and also techniques for processing the records have so far been developed for these applications [*Tucker*, 1953; *Caldwell*, 1948]. These wave recorders fall broadly into three categories: (1) underwater types, (2) surface types, and (3) aerial types. In the underwater type of installation an inverted echo sounder is sometimes used, but more often a pressure-actuated device is employed. This type utilizes the pressure change at the sea bottom at a depth between 40 to 80 ft due to the passage of the wave. The pressure change can be measured by bourdon tubes, strain gages, or piezoelectric and moving coil transducers. Since the bottom-pressure fluctuation p, corresponding to a surface wave of amplitude a_0, is given by $p/a_0 = \text{sech}\ (2\pi h/\lambda)$, where h represents the depth of the water, and λ the wave length [*Tucker*, 1953], this type of pressure actuation will not respond to waves of short wave lengths. Although this factor is not a serious disadvantage where the main interest is in the longer waves, such as in the study of long swell from a distant storm, it is necessary to use other types of recorders where a true picture of the surface wave is desired. For experimental studies on models, the surface type is the only one that can be used.

There are several types of wave recorders of the surface type. Most of them use the property of conductivity of the sea water. The parallel wire gage and the step resistance gage type of wave recorders [*Caldwell*, 1948] depend on the variation in resistance between a pair of wires with changes in the level of sea water.

The wave recorder described in this paper is a surface type of wave recorder and is based on the principle that the capacitance between the sea water and an insulated conductor placed vertically in it varies with the changes in level of the sea water. An instrument based on this principle where the change in capacity is measured directly has been described by *Tucker* [1953]. The instrument described here utilizes a different technique for recording the variations in the capacitance and has a high sensitivity and flexibility in its application.

GENERAL DESCRIPTION OF THE INSTRUMENT

Capacitance-wire electrode—The capacitance-wire electrode used in this instrument consists of a straight wire surrounded by a polythene insulator of uniform thickness. This is obtained by removing the outer protective covering as well as the outer shield of a standard coaxial cable, such as RG-9u, used in u h f work. The central conductor along with the polythene insulator is passed through a tight fitting glass tube. This, when dipped in sea water, forms the inner conductor. A thick copper wire fixed to a zinc grid at the other end is dipped in the sea water, and this connects the outer conductor, which is the sea water, to the measuring device. For tests in the laboratory the electrodes were placed in a large glass tube which was filled with salt water to the desired level (Fig. 1).

Measurement of variation in capacitance—Figure 2 shows the schematic circuit diagram of the instrument. The technique employed here for recording the variation in capacitance of the electrode is to use this capacitance across the tank circuit of a self oscillator so as to produce a frequency modulation of the oscillator output and then to demodulate the frequency modulated signal so as to convert it into an electrical voltage which is a replica of the sea wave. With the type of capacitance wire used here, the capacitance change per foot variation in the level of water is 22 $\mu\mu f$. If the oscillator employed is an audio one, the change in frequency produced by this variation in capacitance is too small to be any use. Hence a radio frequency oscillator operating at a frequency of about 1 mc/s is used. The oscillator is a conventional Hartley oscillator and is well shielded to avoid stray effects. The tank condenser consists of a 500-$\mu\mu f$ fixed and a 50-$\mu\mu f$ trimmer condenser. The two terminals of the capacitance-wire electrode are connected between the ground and a tap on the tank coil (points 1 and 2 of Fig. 2). If C_e represents the capacitance of the capacitance-wire electrode including the capacitance of the coaxial shielded cable connecting it to the instrument, and C_c the coupling capacitance to the tank coil and C_0 the tank capacitance (Fig. 2), it can be shown that the fractional change Δf in the frequency f produced for a change of one foot in the water level (when the electrode is tapped across the full tank coil) is

$$\Delta f/f = \frac{C_c^2 \Delta C_e}{2(C_c + C_e)^2} \Big/ C_0 + \frac{C_c C_e}{C_c + C_e}$$

where ΔC_e is the change in capacitance of the electrode for a change of one foot in the water level. If $C_e = 350$ $\mu\mu f$ and $C_0 = 500$ $\mu\mu f$, Δf is found to be about 0.95 kc/s when C_c is 100 $\mu\mu f$, and 0.32 kc/s when C_c is 50 $\mu\mu f$, for $\Delta C_e = 22$ $\mu\mu f$ and $f = 1$ mc/s.

The function of the coupling capacitance C_c is to control the sensitivity of the instrument and also to reduce the effect of the electrode system on the Q of the tank circuit of the self oscillator. The tap on the oscillator coil can also be used for controlling the sensitivity. The length of the electrode tried out so far has been about six feet, and the length of the coaxial shielded cable connecting it to the instrument has been about 12 ft. Longer lengths of connecting cable can be used, but the sensitivity will be decreased.

Measurement of change in frequency—In order to measure the change in frequency Δf accurately, the output of the variable oscillator is heterodyned into a lower frequency by the use of a fixed r f oscillator operating at about 1 mc/s. This oscillator is also well shielded and has trimmers for adjusting the heterodyned frequency. The heterodyned output, which is in the audio range, is amplified by the voltage amplifier V_4 and fed on to a counter circuit which provides a d c output proportional to the frequency.

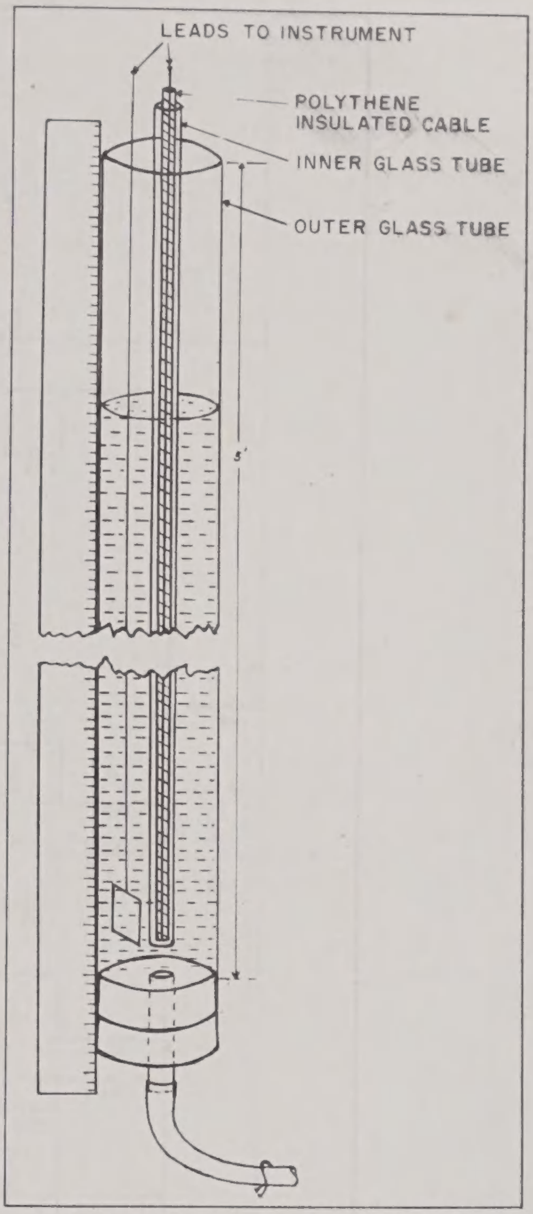

FIG. 1 – Laboratory test set-up of the capacitance-wire electrode

The counter circuit suitable for the frequency measurement is of the type used in the frequency-modulated radar altimeter *AN/APN/1* [*Luck*, 1949]. The heterodyned output from the frequency converter V_2 is amplified by the voltage amplifier V_4 and fed to the limiting stage V_5. Because of the large amplitude of the signal applied to the grid, square wave voltage will be produced at the anode of V_5, and this tube will be switched on and off for half cycles of the input signal. When V_5 is switched off, the capacitance C_s will get charged through the resistor R_0, diode V_7, and the resistor R_1. When V_5 is switched on, C_s discharges through the limiter V_5 and the diode V_6. Part of the current flowing through C_s, when it is getting charged, builds up a voltage across C_1. This voltage is proportional to the number of times C_1 is charged per sec, that is, to the frequency. The voltage output across C_1 is applied to the cathode follower V_8

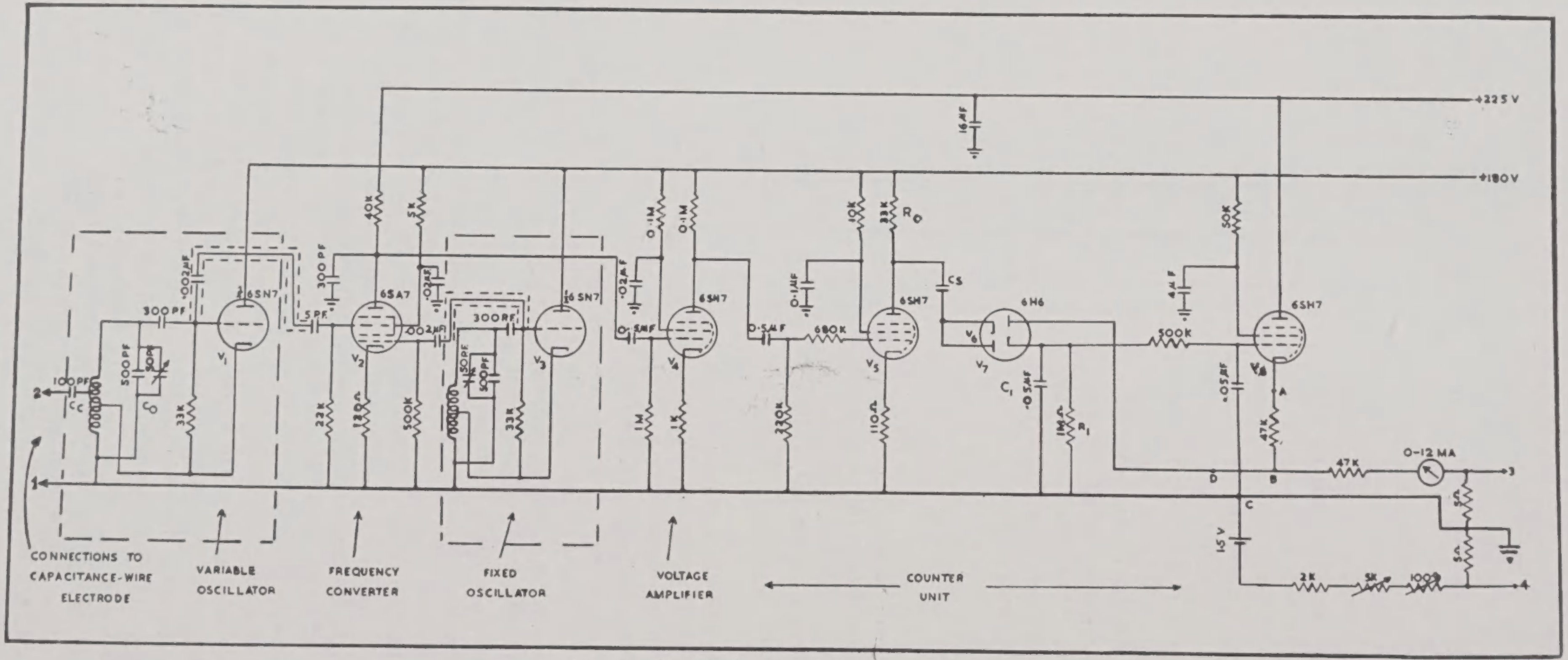

FIG. 2 – Circuit diagram of the electronic unit

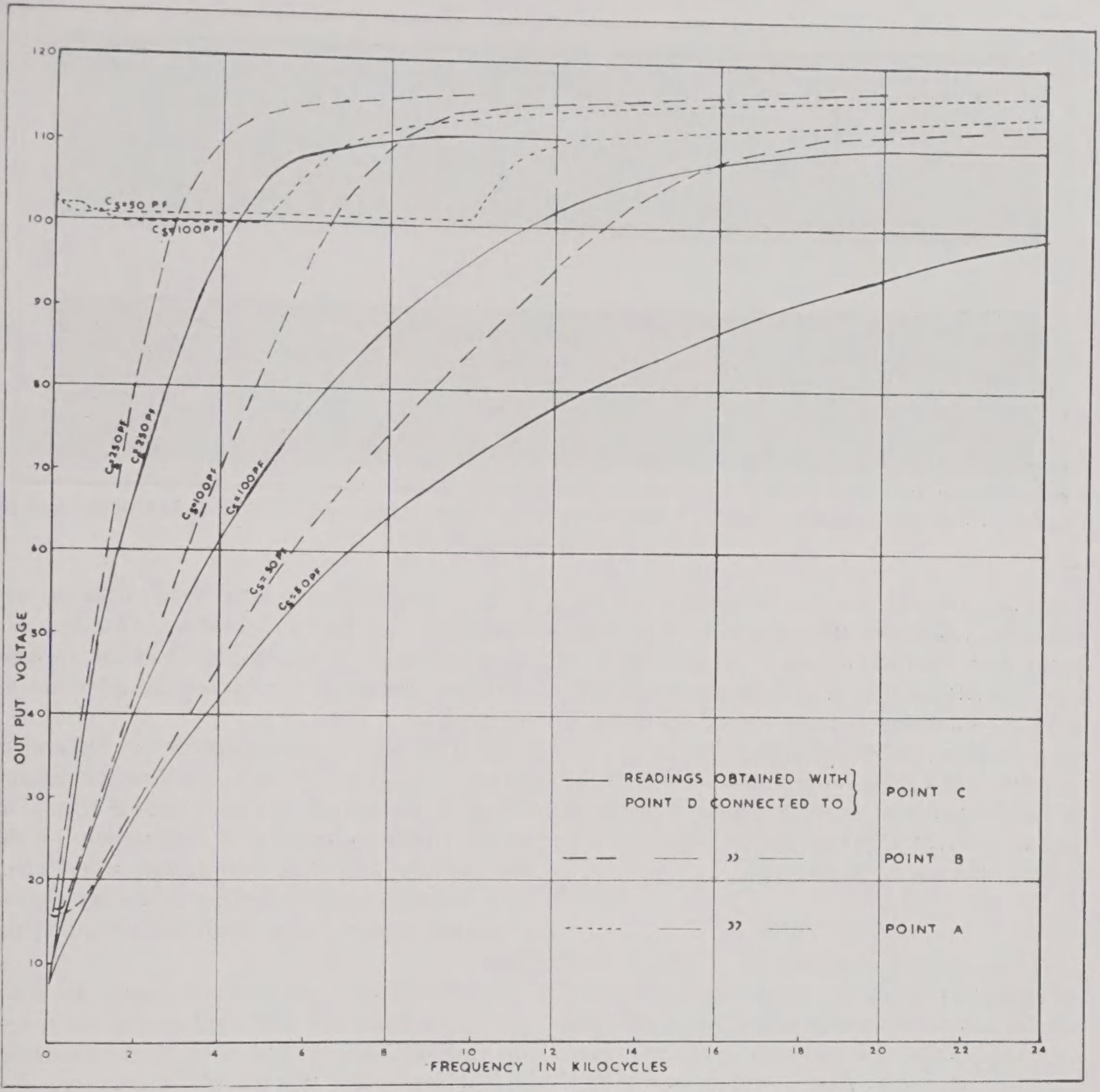

FIG. 3 – Output voltage-frequency characteristics of the counter unit

which provides an output of low impedance. The effect of placing the anode of the discharge diode V_6 at various positive voltages will be to alter the 'output voltage-frequency' characteristics. It is seen from Figure 3 that a fairly linear relationship can be obtained by connecting the point D to B. The effect of C_s on the output voltage-frequency characteristics can also be seen from Figure 3. Large values of C_s give an increased sensitivity but saturation limit is reached for lower frequencies. Optimum value of C_s for this application is 50 $\mu\mu f$, but this value can be increased to 100 $\mu\mu f$ where the frequency range to be covered is lower.

Recording equipment.—The d c output of the cathode follower can be connected to the Y plates of a cathode ray oscilloscope having a d c amplifier. The time base of the oscilloscope should be switched off. The sea waves cause the spot on the oscilloscope to move up and down, and this is photographed, using an oscilloscope camera, on a 35-mm film which is moved at any convenient speed. The type of record obtained while studying the locally generated waves at the entrance to Cochin Harbor is shown in Figure 4. Two speeds have been used for this recording. It is seen that, with this type of recording, waves of any period can be recorded. The output of the cathode follower can also be adopted for recording with a galvanometer type of recorder. The cathode current of the cathode follower V_8 is passed through a five-ohm wire-wound resistor. The standing d c voltage across this is balanced by using another five-ohm resistor through which an adjustable d c current is passed. The output between terminals 3 and 4 of the elec-

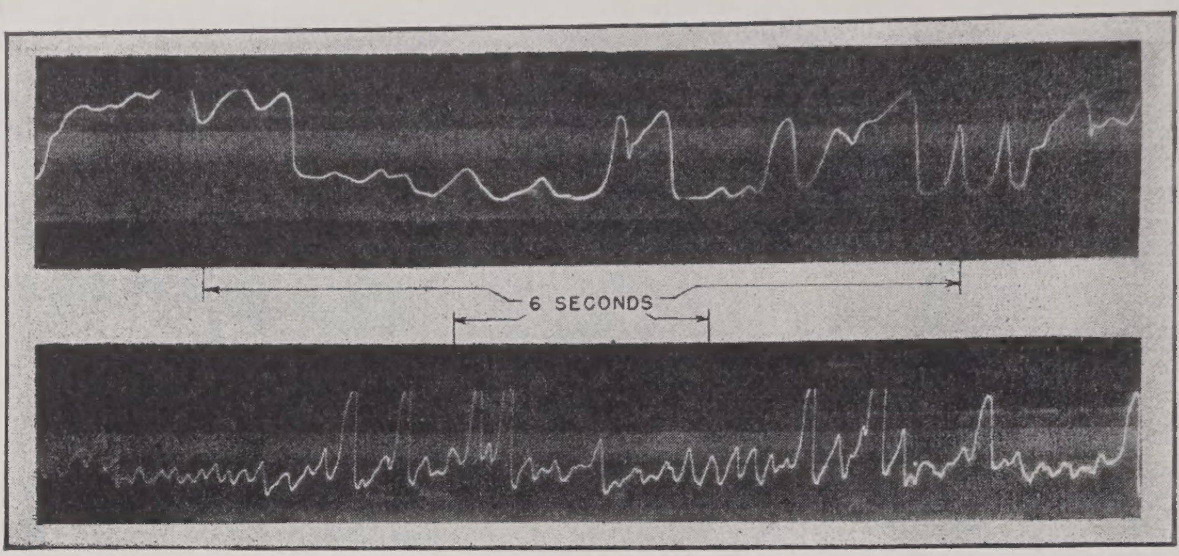

FIG. 4 – Oscillographic record of the locally generated waves at Cochin Harbor; the full-scale deflection corresponds to a wave amplitude of one foot

tronic unit (Fig. 2) can then be applied to a galvanometer recorder of the pen and ink type, such as the Edin recorder, or one of the photographic type. The latter is to be used if the spectrum analysis of the waveform is to be carried out using a wave analyser [*Barber* and others, 1946].

For the instrument power supply, it is desirable to use dry batteries for both filaments and high tension to avoid variations in the frequency due to fluctuations in the main supply.

CONCLUSIONS

(1) This type of wave recorder is suitable both for laboratory study on models of harbors and beaches and for the study of sea waves. For the latter application, it is necessary to fix the capacitance-wire electrode onto a suitable stable supporting structure of the type described by *Gerhardt* and others [1955], at a site where the depth of water is about 40 ft. The length of the capacitance wire should be such that the bottom of the wire is below the lowest wave trough to be expected and the top above the highest crest. The electronic unit of the wave recorder and its dry battery power supplies should be mounted on the structure itself and the leads to the galvanometer recorder taken by means of an armored cable to the shore. A modification can also be carried out so as to use a radio link and to avoid the use of the connecting cable. The electronic unit can then be split into two sections. The section consisting of the capacitance wire and the variable oscillator with a suitable buffer amplifier, dry battery, and aerial, can be located at the supporting structure. The remaining part of the unit, which will consist of an aerial, rf amplifier, converter, fixed oscillator, and the counter, can be located ashore. Thus by radiating the signal at the frequency of the variable oscillator, the use of the connecting cable can be obviated.

(2) This type of wave recorder can respond to waves of all frequencies and can follow the rise and fall of the water surface with negligible error. The overall frequency response is limited only by the galvanometer recording device, and, where steep wave forms are encountered, cathode ray oscilloscope and camera can be used for recording the waves.

(3) The effect of tides can be overcome by introducing a suitable coupling condenser at the grid of the cathode follower. The value of the condenser should be so chosen that waves of the lowest period of interest are passed.

(4) The frequencies of the two oscillators of this unit are fairly stable as battery supplies are in use both for filaments and high tension. The changes in frequency due to changes in temperature and humidity are of such low magnitude and are also spread over such a long time interval that their effect can normally be ignored.

(5) The performance of the capacitance-wire electrode is fairly reliable and comparatively free from the action of the sea water, unlike the other types of surface wave recorders which are very much affected by the sea water.

(6) This wave recorder is extremely sensitive. The sensitivity can be adjusted by varying either the coupling condenser C_e or the tap on the oscillator coil (Fig. 2). With the maximum sensitivity

setting, waves of amplitude of a few inches can be recorded.

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Naval Physical Laboratory, Cochin 4, India

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